How fertile are semi-arid tropical soils?

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The semi-arid tropical (SAT) regions are notably characterized by low rainfall and high temperatures, and hence low natural primary productivity and soil fertility. However, to adequately respond to the title of our article as to how fertile are SAT soils, there is a need to critically review the current literature on the fertility status of SAT soils. Little attention has been paid in the past to determining the fertility status of SAT soils supporting rainfed production systems despite the fact that the SAT soils are relatively fragile than their irrigated counterparts; and this is due to their widespread degradation and lack of investment in building up the fertility. However, as in the case of other agroecosystems, the soils in the SAT regions vary widely in various fertility parameters. For example, the results of survey of large numbers of farmers' fields in the SAT regions of India, by the ICRISAT and its partners, showed that they vary widely in soil pH, salts (electrical conductivity, EC), organic C (an index of available N) and major (N and P), secondary (S) and micronutrients (B and Zn) although the soils were low in organic C with widespread deficiencies of these nutrients. From the results discussed in this article, it is concluded that in general, the soils in the SAT regions are low in fertility; however, they vary widely in various fertility parameters.

Keywords: Farmers' fields, fertility status, organic carbon, major and micronutrients, semi-arid tropics, soil testing.

Introduction

IT is a common practice to make general statements on the fertility status of soils, for example those belonging to an agroecosystem based on not sufficient number of samples to cover in a district, state or country, whatever the case might be, it happens. Soil scientists involved in mapping soil nutrients know as to what is the minimum number of samples need to be collected, e.g. to represent the soils of a district for interpolation of the results for preparing nutrient maps. The details of the method used for collecting representative soil samples from farmers' fields in watersheds, and their analyses are described earlier[1].

Similarly, to be able to comment appropriately on the fertility status of soils of the semi-arid tropical (SAT) regions of India, there is a need to review the past literature critically, analyse and interpret the results. In this article, we review the past literature on chemical fertility with the purpose of gleaning out the salient results emerging from the current literature, and use them to describe the fertility status of soils. For this review, the results on the soil fertility status of samples collected from farmers' fields will be preferred over those from the research stations. However, it must be stated at the outset that little attention has been paid to determining the fertility status of soils supporting rainfed production systems in the SAT regions of India[2]. Selected relevant examples of research done in other SAT regions of the globe will also be included.

Fertility status of SAT soils: some results

The soils in the rainfed areas of SAT globally occur in regions with relatively low rainfall and high temperatures; and as a result these soils support sparse vegetation and have low natural primary production. It follows from this that the SAT soils are relatively low in their inherent natural fertility, but it does not mean that they are not productive. But water shortage in the rainfed SAT is also a major constraint to reckon with, which not only controls productivity but also the maintenance of soil fertility; and Indian SAT is no exception[3–8]. It follows from this that for sustainably enhancing the productivity of rainfed areas in the SAT regions, both water shortage and soil infertility problems need to be simultaneously addressed[2,8].

As an example of the fertility of SAT soils in the rainfed areas, we cite the case of Karnataka state, India. The state has the largest area under rainfed cropping following Rajasthan. Moreover, the ICRISAT in partnership with the government of Karnataka, state agricultural universities and non-governmental organizations completed the sampling of soils from the farmers' fields representing all the 30 districts of the state. The soil samples were analysed for various chemical soil fertility parameters including pH, electrical conductivity (EC), a measure of salts in the soil, organic C (an index of N availability) and extractable P, K, S, B and Zn following the standard methods of soil analyses[2].

The results on the analyses of 92,904 soil samples from all the 30 districts of Karnataka for various fertility parameters are summarized in Table 1. The results on the range, mean, % deficient (percentage of soil samples deficient in a plant nutrient) for soil pH, EC, organic C, and extractable (or available) nutrient elements (Table 1)

*Deceased.

Table 1. Summary of the results on chemical characteristics of soil samples collected from farmers' fields covering all the 30 districts of Karnataka. The results on fertility parameters in terms of range, mean and percentage of samples deficient in parameter are presented district-wise

District	pH	EC (dS m^{-1})	OC (%)	Av P (ppm)	Av K (ppm)	Av S (ppm)	Av Zn (ppm)	Av B (ppm)
Bagalkot (2440)[a]/Range	6.3–8.9	0.11–1.99	0.18–1.23	0.6–6.2	17–74	4.1–39.9	0.50–10.69	0.12–12.78
/Mean	7.8	0.35	0.62	2.3	60	11.7	0.92	0.70
/% samples deficient			36	97	28	59	55	69
Bangalore rural (4448)	4.2–9.5	0.01–9.96	0.01–1.50	0.0–543.8	9–1,414	0.5–2,299.1	0.05–235.00	0.02–5.12
	6.3	0.28	0.41	18.0	100	6.8	1.50	0.37
			73	21	23	90	29	79
Bangalore urban (2680)	4.4–8.7	0.02–2.20	0.03–3.00	0.7–351.5	2–580	0.8–335.0	0.03–5.79	0.02–6.86
	6.7	0.19	0.49	43.0	125	29.3	1.30	0.60
			58	10	14	6	37	60
Belgaum (4560)	4.7–8.9	0.04–5.11	0.02–2.62	0.0–15.3	0–169	0.2–460.0	0.02–3.48	0.01–3.29
	7.3	0.44	0.64	2.1	52	152.2	0.66	0.59
			29	95	52	2	68	74
Bellary (2100)	6.2–9.0	0.10–2.25	0.20–1.24	0.6–6.2	16–74	4.1–41.4	0.52–13.81	0.12–18.02
	7.4	0.40	0.63	2.9	55	11.1	1.27	1.20
			32	90	33	67	19	36
Bidar (2375)	5.5–9.5	0.03–4.04	0.12–1.98	0.6–118.6	18–2,297	1.0–181.3	0.16–18.00	0.10–6.18
	7.6	0.24	0.59	8.4	208	7.3	0.85	0.55
			40	48	1	83	62	66
Bijapur (2791)	6.1–9.4	0.05–78.00	0.02–1.50	0.1–91.9	24–2,613	0.9–4,647.4	0.12–10.40	0.02–18.22
	8.3	0.40	0.42	3.8	209	24.4	0.50	0.93
			70	81	3	77	89	43
Chamarajanagar (1640)	5.1–9.7	0.02–8.00	0.04–1.85	0.2–121.6	20–766	0.4–119.4	0.14–6.40	0.02–3.80
	7.7	0.29	0.41	10.0	188	6.3	0.73	0.58
			76	37	4	87	67	62
Chikkaballapur (2257)[a]	4.5–9.9	0.01–16.62	0.07–1.42	0.2–430.8	4–1,650	0.5–470.0	0.06–21.50	0.06–1.98
	6.9	0.19	0.39	18.0	95	9.1	1.15	0.38
			78	37	34	80	52	80
Chikmagalur (4140)	2.9–9.8	0.01–1.89	0.01–2.45	0.5–129.2	1–304	1.0–2,425.0	0.01–6.75	0.02–55.44
	6.5	0.13	0.62	17.6	82	31.7	0.59	1.46
			48	15	44	34	77	43
Chitradurga (1489)	4.7–10.1	0.01–4.11	0.03–1.36	0.2–480.0	12–1,953	0.8–291.8	0.08–40.50	0.04–6.94
	7.8	0.23	0.40	7.0	137	7.3	0.64	0.63
			76	54	15	86	80	64
Dakshina Kannada (1418)	4.8–8.3	0.01–1.38	0.04–3.63	0.1–364.2	1–336	0.2–613.6	0.01–8.94	0.01–22.08
	5.5	0.09	1.26	12.6	46	38.5	0.84	1.66
			2	29	71	21	65	44
Davanagere (2968)	4.2–9.9	0.01–6.74	0.04–2.70	0.2–95.4	11–480	0.9–99.7	0.04–4.80	0.02–3.00
	7.0	0.22	0.49	14.0	108	10.4	0.69	0.54
			59	30	12	76	74	64
Dharwad (1129)	5.1–9.3	0.03–1.91	0.17–1.99	0.2–207.0	36–2,344	1.4–715.0	0.24–24.30	0.10–12.48
	7.4	0.24	0.65	9.3	220	9.7	0.98	0.82
			31	53	1	79	44	39
Gadag (1270)	5.1–9.6	0.04–5.53	0.04–1.41	0.0–82.8	27–1,145	0.4–223.3	0.06–7.98	0.10–9.62
	8.2	0.27	0.41	5.3	185	7.1	0.42	0.88
			75	65	2	85	92	34
Gulbarga (3640)	4.9–9.8	0.05–34.50	0.04–2.50	0.2–88.7	19–1,722	0.4–12,647.9	0.10–5.18	0.02–24.90
	8.0	0.34	0.49	5.7	266	28.1	0.53	0.63
			60	64	1	83	86	71
Hassan (10274)[a]	3.9–9.7	0.03–3.60	0.04–5.71	0.2–363.0	9–1,394	0.2–515.1	0.06–41.90	0.02–4.08
	6.3	0.24	0.58	19.4	116	8.4	1.12	0.32
			48	23	18	82	50	91
Haveri (1532)	5.1–10.5	0.03–2.34	0.08–3.60	0.1–143.0	25–3,750	0.3–120.3	0.20–34.10	0.08–8.44
	7.7	0.18	0.51	12.4	133	7.0	0.81	0.71
			55	42	5	85	60	46
Kodugu (1160)	4.0–7.8	0.01–2.06	0.28–1.26	1.2–15.5	0–223	1.1–206.5	0.03–37.30	0.03–11.75
	5.6	0.07	1.15	7.0	53	12.7	4.13	1.21
			0	59	68	74	24	28
Kolar (2161)	4.6–10.2	0.02–13.00	0.04–1.50	0.0–182.0	9–1,144	0.7–141.2	0.14–14.40	0.04–1.82
	7.0	0.16	0.38	20.3	87	7.0	1.31	0.34
			81	31	34	85	32	87

(*Contd*)

Table 1. (*Contd*)

District	pH	EC (dS m^{-1})	OC (%)	Av P (ppm)	Av K (ppm)	Av S (ppm)	Av Zn (ppm)	Av B (ppm)
Koppal (2499)	5.2–9.8	0.01–5.70	0.03–2.90	0.0–214.6	24–708	0.3–1,482.5	0.01–20.09	0.01–2.98
	7.7	0.26	0.45	19.6	147	82.5	0.84	0.30
			65	7	2	22	59	87
Mandya (5479)	4.5–8.9	0.01–3.10	0.01–1.26	1.5–27.2	7–164	1.0–278.3	0.01–4.86	0.01–3.98
	6.8	0.39	0.59	15.1	103	43.3	0.62	0.60
			43	14	6	27	71	65
Mysore (4860)	3.2–9.3	0.01–3.20	0.03–1.26	0.4–15.7	3–168	0.9–1,459.8	0.01–19.80	0.03–14.73
	6.8	0.18	0.43	10.1	129	59.7	2.13	0.68
			69	25	3	13	26	60
Raichur (3343)	4.8–9.8	0.02–56.90	0.03–1.60	0.0–169.6	13–1,797	0.8–49,083.7	0.12–15.24	0.01–34.34
	8.2	0.60	0.42	11.1	202	177.2	0.66	1.17
			71	48	4	64	79	39
Ramanagara (3068)[a]	3.2–8.4	0.03–1.71	0.03–3.00	0.5–378.2	3–631	0.3–2,675.0	0.01–9.52	0.01–20.68
	6.4	0.16	0.41	25.4	104	175.0	1.05	0.32
			70	5	15	13	48	88
Shimoga (6140)	3.8–8.2	0.01–2.32	0.07–3.15	0.7–90.5	2–175	0.5–99.5	0.07–20.00	0.01–31.76
	5.6	0.13	0.71	8.8	80	15.8	1.03	0.80
			23	41	46	34	36	36
Tumkur (3041)	2.8–10.0	0.01–14.00	0.04–2.08	0.1–204.0	11–1,470	0.1–128.4	0.14–17.26	0.03–3.60
	6.6	0.13	0.39	5.9	92	5.5	0.89	0.33
			77	65	34	92	50	91
Udupi (1000)	5.4–7.0	0.10–0.59	0.36–0.99	1.5–14.2	20–169	3.1–25.5	0.12–4.18	0.11–3.55
	6.0	0.26	0.81	3.6	71	10.3	0.94	0.52
			4	85	34	54	51	69
Uttar Kannada (4980)	3.5–8.4	0.01–5.00	0.08–9.58	0.1–47.1	0–199	0.1–470.0	0.02–26.40	0.02–290.00
	5.5	0.12	0.56	6.4	64	81.6	0.95	4.05
			46	41	45	28	53	48
Yadgir (1982)	5.0–10.0	0.03–8.78	0.01–1.19	0.0–97.3	14–1,558	0.9–237.4	0.12–14.80	0.02–4.60
	7.9	0.35	0.40	9.6	204	26.8	0.49	0.66
			74	48	5	72	90	58
Karnataka state (92904)	3.5–10.0	0.03–8.78	0.01–9.58	0.0–543.8	0–3,750	0.9–237.4	0.00–235.00	0.02–4.60
	6.8	0.25	0.54	12.5	115	44.4	1.01	0.87
			52	41	23	52	55	62

[a]Values in parentheses are the number of farmers' fields sampled.

Table 2. Critical limits in the soil of various plant nutrient elements to separate deficient samples from non-deficient samples. The data gleaned from various literature sources[10,11]

Plant nutrient	Critical limit (mg kg^{-1})
Sodium bicarbonate-extractable P	5
Ammonium acetate-extractable K	50
Calcium chloride-extractable S	8–10
Hot water-extractable B	0.58
DTPA-extractable Zn	0.75

show that soil samples had a range in pH, EC, organic C and in extractable P, K, S, B and Zn.

It is important to note that to separate deficient soils from the sufficient ones in a particular plant nutrient, the critical limits, gleaned from published literature, in the soil for each plant nutrient given in Table 2 were used[9–11].

The results further show that the soil samples were low in organic C (hence in available N), and widely deficient in P, S, B and Zn, but the deficiency of K was of minor nature. These results are in accord with the results of soil analysis reported from other states of India including Andhra Pradesh, Rajasthan and Madhya Pradesh[8,10–13].

In the semi-arid regions of sub-Saharan Africa, soil fertility has been mainly focused on organic matter and major nutrient management, and little research has been reported on the extent of deficiencies of secondary and micronutrients. As in the case of Indian SAT, the soils in sub-Saharan Africa are low in organic C and acutely deficient in P and K, especially soils in the drier areas of the regions. This is due to lack of inputs of organic matter and nutrients from external sources. However, an integrated nutrient approach that combines the use of mineral and organic sources of plant nutrients has been recommended following extensive studies in the region. As mentioned earlier, most studies have focused on the role of N, P and K deficiencies in the production systems (for review see refs 5, 6).

Perspectives

From this discussion it follows that soils of the SAT regions in India vary rather widely in various fertility parameters; and it would be hazardous to generalize that the soils occurring in the SAT regions of India are low in fertility as selected soils are sufficient or relatively high organic C and extractable S, B, Zn and P. In fact, most soil samples from farmers' fields seem sufficient or high in extractable K (Table 1). Having said that, it is also fair to state from the results that the SAT soils from Karnataka are low in organic C and widely deficient in extractable P, S, B and Zn.

For sustainably enhancing the productivity of rainfed areas in the SAT regions, it is a prerequisite to maintain soil fertility relative to organic C, major and micronutrient status; indeed, balanced and integrated nutrient management approach holds the key not only to maintaining soil fertility in the longer-term, but also promotes efficient use of rainwater for enhancing agricultural production and productivity. Soil fertility is critical for enhancing productivity and crop and food quality[2,14]. Moreover, there is a direct connection between soil health and food quality, and in turn between food quality and human health via food chain[15].

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